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7. RECEIVING ENVIRONMENT: ONSHORE

This chapter describes the onshore receiving physical, terrestrial biological and freshwater aquatic biological environment associated with the Papua LNG Project - Downstream (the Project). The onshore component of the Project is located at the LNG Plant at Caution Bay, 20 km north-west of Port Moresby on the south coast of Central Province in Papua New Guinea. The onshore baseline environment for the Project is a disturbed area, which was cleared in the early twentieth century for agriculture and contributed to by the construction and operation of the LNG Plant and associated facilities.

Baseline investigations were undertaken before the construction of the LNG Plant to support the PNG LNG Project Environmental Impact Statement (EIS). The LNG Plant and associated facilities are a predominant feature of the landscape as shown in Plate 7.1, Plate 7.2 and Plate 7.3. Onshore investigations for the PNG LNG Project EIS included a number of environment studies including: soils and landforms, groundwater, hydrology and sediment transport, water and sediment quality, air, noise, terrestrial biodiversity and aquatic fauna. In 2019 and 2022, additional studies for groundwater, hydrology (flood modelling), weeds and wallabies, air and noise were undertaken to inform the preparation of the Project EIS and supplement the baseline data that was collected for the PNG LNG Project. These studies were specifically tailored for environmental aspects to fill information gaps for the Project. Further field studies were not undertaken for other environmental aspects as available information is adequate for the Project impact assessment.

Marine field studies were completed for the Project and are summarised in Chapter 8 Receiving Environment: Marine and results from resource use studies are summarised in Chapter 9 Social Environment.

Baseline summaries in this chapter, as well as chapters 8 and 9, are based on studies completed for the PNG LNG Project EIS, studies completed for the current Project, and also consider monitoring data collected post-construction of the LNG Plant including for water resources, terrestrial and aquatic ecology, and ambient noise and air quality.

7.1 PHYSICAL ENVIRONMENT

The physical environment of the LNG Plant and surrounds is described for the following aspects: landform, soils, geology, groundwater, seismicity, climate, surface water, air quality and noise.

7.1.1 Landforms

The landform around the LNG Plant is a coastal plain with low hills of predominantly savanna and grassland, sloping gently seaward. This area was largely cleared of vegetation in the early 20th century for agricultural purposes. Construction of the LNG Plant was completed in 2014, including land clearing within the project footprint. Most of the area outside the LNG Plant security fence remains substantially modified due to frequent grassfires that occur during the dry season, restricting the recovery of naturally occurring eucalypt woodland.

A coastal strip of mangroves exists on the shoreline, which includes beach ridges that support forest patches and grassland. Behind the mangroves (inland) and beach ridges are open mudflats that receive intermittent tidal inundation during spring high tides via the Vaihua River and tidal creeks. When not inundated, the mudflats become dried and are called salt flats. Behind the swamps and mudflats, the land rises gently into savanna grassland vegetation that has been invaded by patches of weeds. Further inland, open eucalypt-melaleuca woodland occurs on low-lying hills, and patches of riparian forest and grassland occupy riverine areas.

Plate 7.1
LNG Plant site facilities looking north-east



Photo credit: Tetra Tech Coffey

Plate 7.2
LNG Plant site with LNG tanks, looking north



Photo credit: Tetra Tech Coffey

Plate 7.3
LNG plant site looking south-east



Photo credit: Tetra Tech Coffey

The LNG Plant and surrounding area are characterised by three distinct land systems defined in the Commonwealth Scientific and Industrial Research Organization (CSIRO) Land Research Series No.14 for the Port Moresby Kairuku area (Mabbutt et al. 1965). These are:

- **Coastal Papa System:** consists of tidal flats, salt flats, estuarine mudflats, dunes and beach ridges on grey clayey or sandy peats to brown sticky clays. It is vegetated with mangroves, other salt tolerant communities and grassland.
- **Boroko System:** lies inland from the Papa system and comprises alluvial plains with cracking grey soils and floodplains with olive silty clays. It is largely cleared with hilly terrain with weak or no structural control.
- **Fairfax System:** covers the eastward and southern parts of the LNG Plant. It consists of low plateaus and hills with undulating plains with brown clay soils. This system is dominated by open eucalypt savanna with narrow strips of riparian forest along the seasonal waterways. The terrain is hilly with weak or no structural control leading onto mountains and hills with weak or no structural control.

Figure 7.1 shows landforms derived from the PNG Resource Information System (PNGRIS) database, which supports these land systems.

Elevation of the terrestrial environment in the Project area and surrounds ranges from sea level along the coastal strip and along the banks of Vaihua River and North Vaihua River, to between 5 and 50 metres (m) above sea level. Overall, the topography slopes from the hills in the east, down to the coast in the west where there is a gradient of generally less than 1 degree (°). Several north-northwest to south-southeast trending hills, known as the Boera Hills, exist south of the LNG Plant.

The LNG Plant lies within the Southern Plains and Lowlands Region of Papua New Guinea that extends from the south coast and north to the foothills of the Central Ranges. Most of the region is dominated by poorly drained or swampy alluvial plains. These plains are traversed by meandering river channels on the floodplain with off-channel waterbodies, such as oxbow lakes and swamps.

The Vaihua River and North Vaihua River traverse the LNG Plant site and discharge to the sea via the Vaihua and the North Vaihua estuaries. Karuka Creek passes through part of the lease area to Mokeke Creek and then to Mokeke Creek estuary.

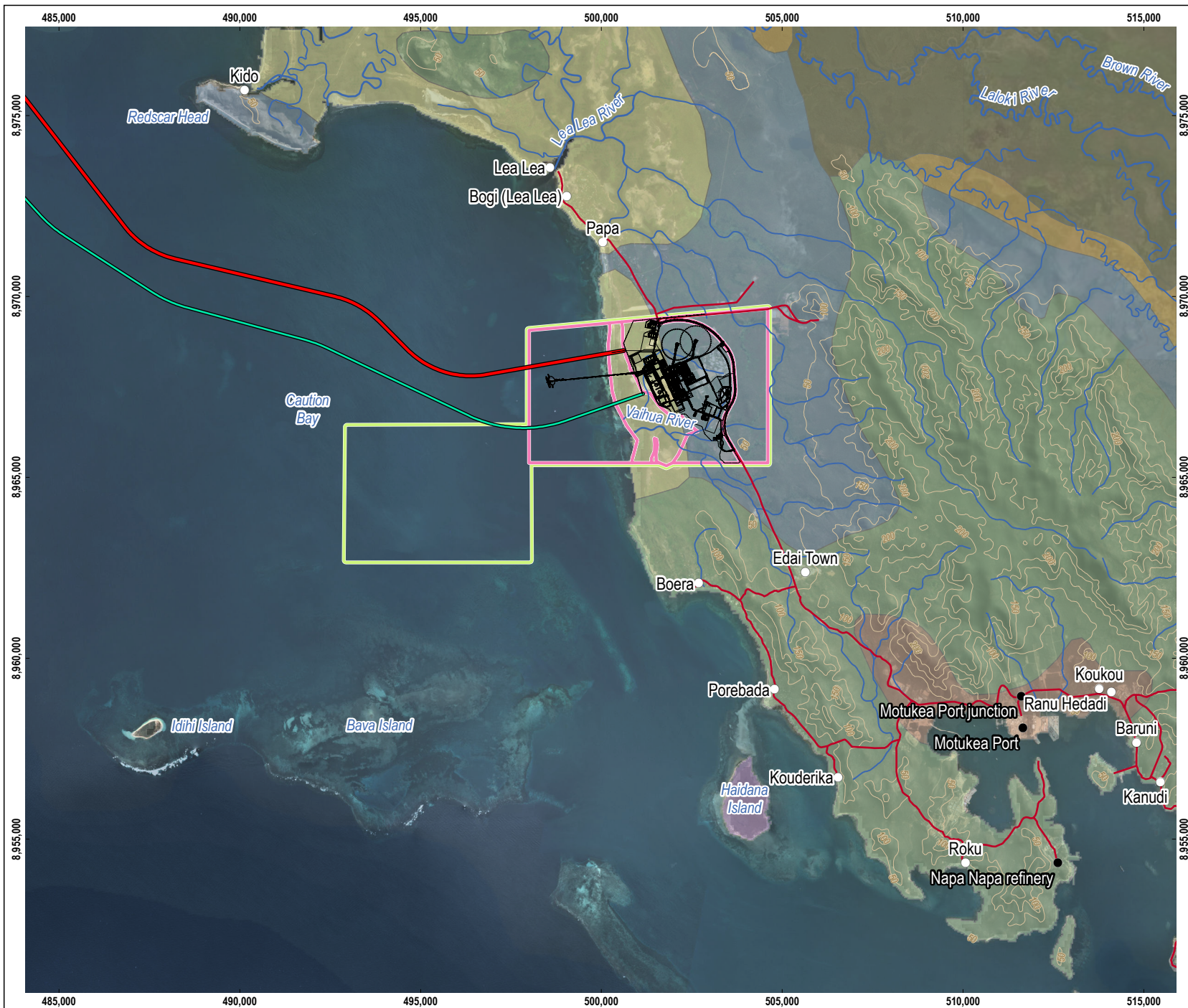
Extensive tidal flats are interspersed with narrow bands of beach ridges and swales near the coast. Mangrove swamps form part of these tidal flats. The surface water environment is discussed in further detail in Section 7.1.7.

7.1.2 Soils

A soil and landform study was conducted as part of the PNG LNG Project in 2008. The study involved the identification of soil profiles, analysis of selected soils for baseline fertility properties and testing for acid sulphate soils (ASS) in selected coastal swamps and soil stability (Booyong Forest Science 2009). The data collected for the PNG LNG Project EIS is sufficient to characterise the soils within the LNG Plant area, therefore no further soil sampling was undertaken as part of this EIS. The distribution of ASS is shown in Figure 7.2.

The study identified two main soil orders:

- **Entisols:** are generally young soils with little or no profile except for a thin humic (organic) surface horizon. These soils are present in the swamps and beach areas of the LNG Plant as shown in Figure 7.2. They are composed of littoral (nearshore) and fluvial (riverine) deposits, including gravel, sand, silt and clay. The sandy soil of the beach ridge comprises thick, poorly graded sands containing shell fragments. In the coastal mangrove area, soils are rich in silt or clay sedimentary layers that have a high content of finely dispersed organic matter intermixed with thick organic layers.



LEGEND

- Village
- Point of interest
- Road
- Watercourse
- Contour (50 m interval)
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary
- Landform
 - Back swamps
 - Composite alluvial plains
 - Hilly terrain with weak or no structural control
 - Mangrove swamps
 - Mountains and hills with weak or no structural control
 - Raised coral reefs and associated back reef plains
 - Undifferentiated coastal plain

SOURCE

Landforms from PNGRIS.
Contours, infrastructure, roads, watercourses and lease boundary from EMPNGA.
Imagery from ArcGIS Online and Planet Labs.



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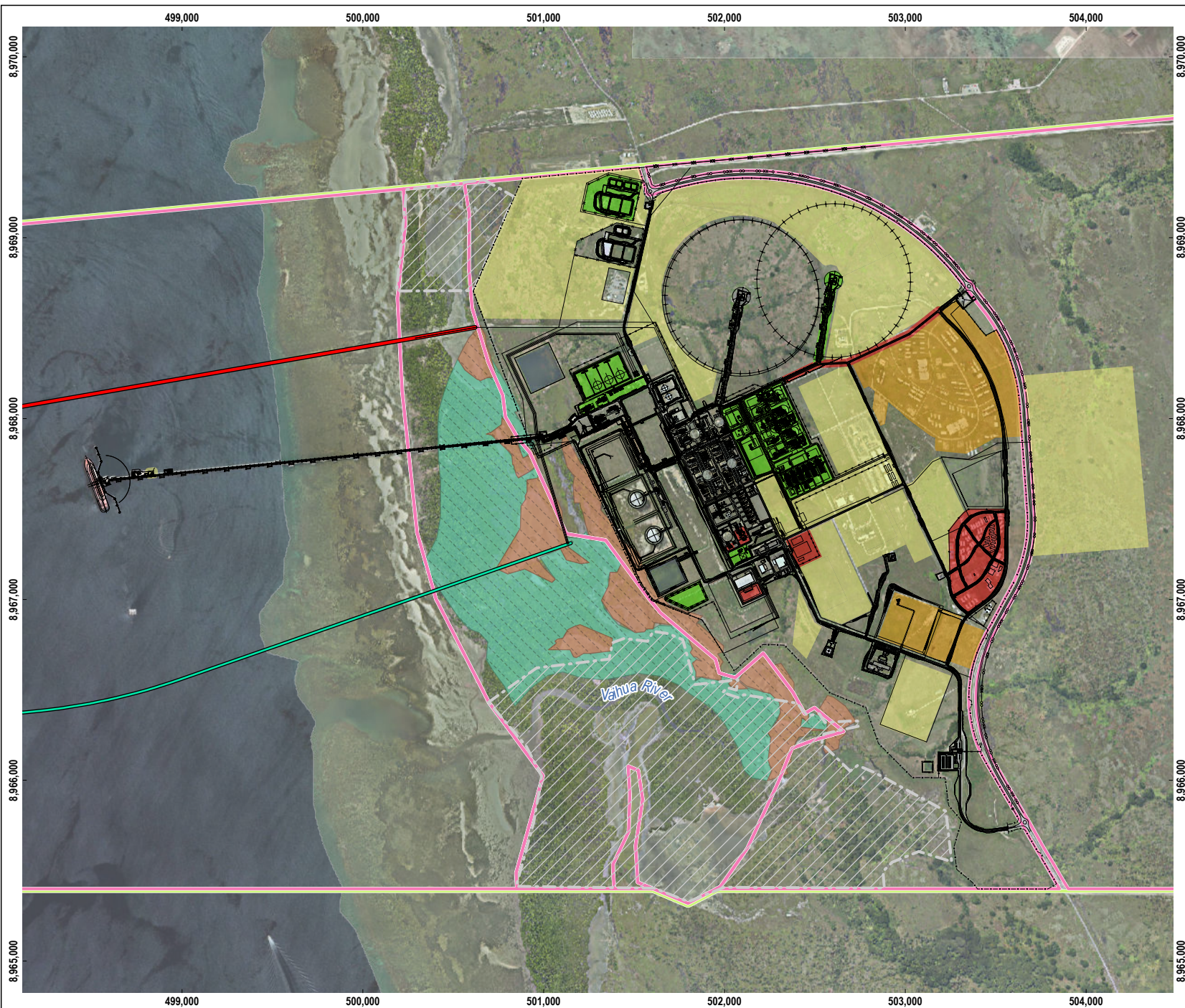
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PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 7.1

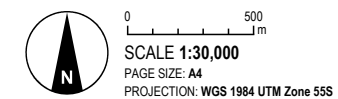
Landforms of the LNG Plant and surrounds





- LEGEND**
- PNG LNG pipeline
 - Proposed Papua LNG pipelines route
 - Existing and proposed plant layout
 - Proposed new facility
 - Proposed expanded/upgraded facility
 - Temporary construction area
 - Temporary camp
 - PPFL2 boundary
 - APPFL boundary
 - Cultural heritage restricted area
 - Potential acid sulfate soils
 - Back swamps
 - Mangroves

SOURCE
 ASS, infrastructure, cultural heritage and lease boundary from EMPNGA.
 Imagery from EMPNGA and Google Earth.



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 PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 7.2
 Distribution of potential acid sulfate soils (ASS) in the Project area and surrounds



Laboratory results have confirmed these soils have ASS potential, containing iron sulphides, which occur naturally, that are stable below the water table where they are not exposed to oxygen (Figure 7.2). These are commonly associated with tidal mangroves. If these soils are exposed to oxygen, leachable sulphuric acid can be generated, potentially leading to the mobilisation of dissolved metals. If these soils are not managed appropriately to limit exposure to atmospheric conditions, a localised impact on vegetation, soil, surface water and groundwater may occur.

- **Vertisols:** are typical in areas with low and seasonal rainfall and occur inland from the coast. They have low permeability due to their high clay content and tend to crack seasonal cycle based on sequential wetting and drying. Known as 'black cracking clays', these soils can be dispersive and erodible if disturbed. Vertisols usually have a high sodium content (sodic soils), resulting in the clays swelling and dispersing. Most of the LNG Plant site is comprised of these soils, as shown in Figure 7.2, east of the area comprising back swamps and mangroves. Polygonal cracking patterns form in surface clays that can become over-consolidated with material falling in the cracks. These cracks, which can be up to 50 mm wide and up to 0.5 m deep, close up in the wet season, creating pressure that can cause heaving of the ground surface. Crabholes (erosion holes) can develop in the clay surface when water drains into open cracks, causing erosion of the clay.

With the exception of sandy soils that have a high porosity and high infiltration rates that reduce their susceptibility to erosive rainfall, all of the soils tested at the LNG Plant site and surrounding area are susceptible to erosion if exposed to high rainfall intensity.

7.1.3 Geology

Figure 7.3 illustrates the lithology and geology of the LNG Plant and surrounding area. South-east Papua New Guinea is geologically complex. It contains metamorphosed sedimentary rocks (coarse and fine grained) of Cretaceous and Jurassic age and also many basic igneous tertiary rocks. The hills and bedrock in the region generally comprise siliceous argillite, chert, calcarenite, mudstone, basalt and tuff, as well as gabbro intrusive in some areas. Alluvial deposits, with thicknesses up to 25 m, have formed within the valleys and depressions in the region of the LNG Plant. Estuarine deposits dominate the area around Lea Lea and Papa to the north of the LNG Plant, including the coastal strip of the LNG Plant and along the river mouths of Vaihua and North Vaihua rivers, which discharge to Caution Bay. Colluvial and talus deposits are present at the base of the hills, interspersed with alluvial clays on the coastal plain.

7.1.4 Groundwater

The following sections are based on the LNG Plant groundwater study undertaken in 2019 presented in Appendix H Groundwater Baseline. The data used in this report is based on data collected as part of the PNG LNG Project EIS and the monitoring data collected for LNG Plant environmental and social management plan (ESMP) requirements to meet the conditions of Environment Permit EP-L3(210).

The current groundwater monitoring network for the LNG Plant site consists of fourteen groundwater monitoring wells. Six of these wells (spaced approximately 30 to 170 m apart) are located in proximity to the landfill, and the remaining eight wells (spaced approximately 250 to 1,000 m apart) are distributed across the LNG Plant area.

7.1.4.1 Aquifers

The main groundwater resources in the vicinity of the LNG Plant are associated with alluvial deposits of the coastal plain (clayey and silty, sand and gravels). Alluvial aquifers hosted by these sediments are 5 m to 15 m thick and are typically overlain by 5 m to 10 m of low permeability clayey sediments.



LEGEND

- Village
- Point of interest
- Road
- Watercourse
- Contour (50 m interval)
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary
- Lithology and geology**
 - Mixed or undifferentiated sedimentary
 - Mixed sedimentary and limestone
 - Limestone
 - Basic to intermediate volcanic
 - Alluvial deposits

SOURCE

Geology from PNGRIS.
Contours, infrastructure, roads, watercourses and
lease boundary from EMPNGA.
Imagery from ArcGIS Online and Planet Labs.



0 1 2 3 km
SCALE 1:150,000
PAGE SIZE: A4
PROJECTION: WGS 1984 UTM Zone 55S

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PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 7.3

Lithology and geology of the LNG Plant
and surrounds



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The alluvial aquifer is expected to contain two separate zones: a perched shallower zone comprising residual clay material overlying bedrock, and a deeper aquifer zone comprising sandstone/gravel layers interbedded with siltstone and shale material. A review of the available monitoring bore drilling logs from 2010 identified sandstone and claystone existed beneath the unconsolidated sediment, up to 15 m thick. It is likely that two regionally extensive groundwater flow systems exist beneath the Project area: a shallow alluvial and a deeper siltstone/sandstone rock (or weathered rock) aquifer (Appendix H Groundwater Baseline).

Hydraulic conductivity in the shallow groundwater zone ranged from 0.001 m/day to 0.1 m/day, with a maximum seepage velocity of 0.01 to 1 m/year to the west and southwest. In the deeper groundwater zone, hydraulic conductivity ranged from 0.0002 m/day to 0.66 m/day, with a maximum seepage velocity of 48 m/year to the west and southwest. These results are within typical values for clay and sandy clay in the shallow aquifer and sandstone lithologies in the deeper groundwater zone.

7.1.4.2 Groundwater level and flow direction

Estimated groundwater levels across the site range from maximums of approximately 29 m Reduced Level (RL) in the east (MW-1, MW-2, GW-16) to minimums of between 2 and 5 m RL to the west site perimeter and coastal zone as shown on Figure 7.4. Groundwater entering from the east is expected to be represented by wells MW-1, MW-2 and GW-16 that migrates beneath the site to the west and south-west towards the coast.

A downward hydraulic gradient was identified based on measured groundwater levels at bores MW-4 (screening the shallow unconsolidated aquifer) and MW-4a (screening the deeper aquifer) that show an approximately 2 m vertical head difference. This may promote the vertical flow of groundwater from the shallow alluvial aquifer downwards, recharging the deeper aquifer.

7.1.4.3 Groundwater quality

As described in a groundwater review for the LNG Plant undertaken in 2021 (Tetra Tech Coffey 2021), the water quality criteria in the ESMP were determined from limited baseline groundwater sampling data collected in 2010. It is expected that the short timeframe (and possibly low frequency) of the baseline monitoring undertaken in 2010 to establish baseline conditions (and the criteria) may not have been sufficient to accurately define the natural variability of some physico-chemical parameters. As a result, what is reported as an exceedance of baseline conditions may not necessarily represent an LNG Plant-related change. A summary of groundwater quality data is provided in Table 7.1 with groundwater criteria specified in the ESMP. There are no groundwater-specific criteria in the Environment Permit.

Long term groundwater quality trends based on data collected between 2010 and 2019 are summarised below.

Groundwater pH has been relatively consistent across the site, generally fluctuating between pH 6.5 to 8. Groundwater salinity is highly variable both spatially across the site and temporally within individual wells. Monitoring wells GW-21 and GW-22, located on the western boundary of the site near the coast, are highly saline, reporting concentrations between 30,000 mg/L and 70,000 mg/L total dissolved solids (TDS), suggestive of marine water influence.

In the vicinity of the LNG Plant, the main contaminants elevated above the criteria in the ESMP were ammonia, hydraulically cross-gradient of the construction sediment pond north-west of the LNG Plant (GW-22), as well as increasing concentration trends of barium (GW-22), manganese (GW-22, GW-21, GW-17), iron (GW-22), ammonia (GW-22) and total nitrogen (multiple wells listed in Table 7.1) were present. Future monitoring will verify whether these trends are significant.

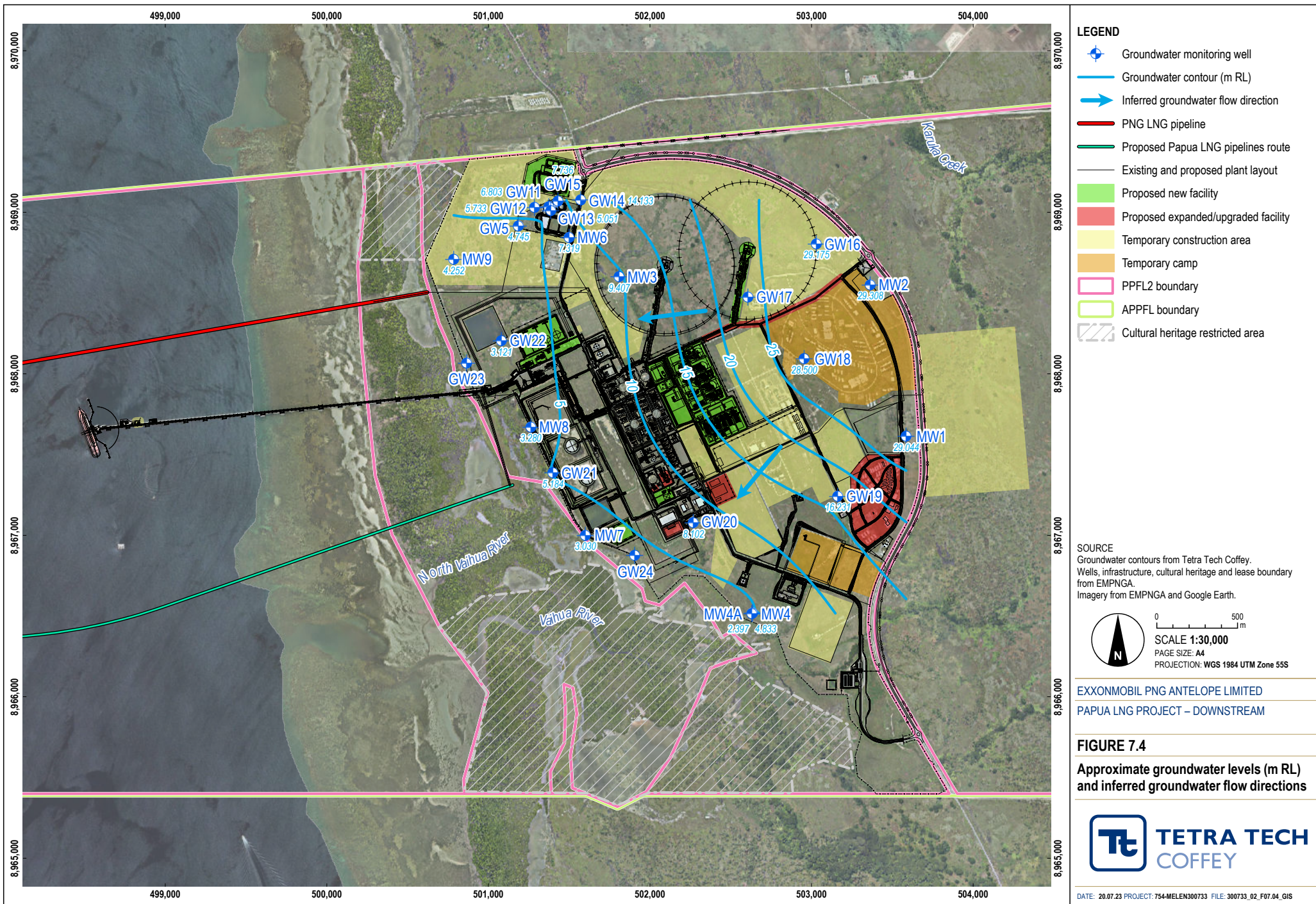


Table 7.1 Summary of groundwater quality data

Parameter	ESMP criteria	PNG DWG (1987)*	Concentration Range (December 2019)	Criteria Exceedances	
				ESMP criteria	PNG DWG (1987)*
Arsenic	<1 – 106	50	<1 – 5	-	-
Barium	<6 – 1,400	NS	32 – 656	-	-
Cadmium	<0.1 – 340	10	<0.1 – <0.5	-	-
Chromium (VI)	<1 – 120	NS	<10	-	-
Cobalt	<1 – 30	NS	<1 – 8	-	-
Copper	<1 – 25	1,500	<1 – 2	-	-
Lead	<1 – 52	100	<1 – <5	-	-
Manganese	<1 – 3,200	500	6 – 4,600	GW21 (4,600)	MW2 (693) GW5 (1,010) GW11 (2,420) GW22 (820) GW23 (1,220) GW24 (1,680)
Nickel	<1 – 40	NS	<1 – 2	-	-
Selenium	<1 – 235	10	<10 – 170	-	GW13 (20) GW20 (170)
Silver	<1 – 200	NS	<1 – <5	-	-
Tin	<1 – 220	NS	<1 – <5	-	-
Zinc	<1 – 95	15,000	<5 – 6	-	-
Boron	1 – 4,600	NS	130 – 1,910	-	-
Iron	<1 – 17,000	1,000	<50 – 12,600	-	GW14 (1,510) GW22 (12,600)
Mercury	<0.1 – 0.3	1	<0.1 – <0.5	-	-
Ammonia nitrogen	0.1 – 7.2	NS	<0.01 – 8.04	GW22 (8.04)	-
Nitrogen (total)	<0.01 – 1.3	NS	<0.1 – 14.2	MW2 (14.2) GW11 (1.4) GW21 (2.3) GW22 (8.4) GW24 (2)	-

* PNG drinking water criteria are based upon total metals. Data collected relates to dissolved concentrations. Direct comparison of dissolved concentrations with these criteria may under report the health risk. Bold text indicates exceedance.

Elevated concentrations of manganese were recorded in monitoring wells downgradient of the landfill area, relative to baseline concentrations and cross-gradient and upgradient monitoring wells. In general, however, manganese concentrations were mostly recorded below the site's ESMP criterion (2,700 µg/L), as were barium concentrations.

A range of field and other parameters (e.g., calcium, magnesium, sodium, ammonia, total nitrogen) were elevated above relevant ESMP criteria in one or more monitoring events for most wells. However, upgradient monitoring well, GW-14, recorded similar deviations from initial baseline ranges for these analytes indicating

such levels may be typical of background conditions hydraulically upgradient of the site. Future monitoring will determine the significance of manganese, ammonia, and total nitrogen trends.

Elevated concentrations of faecal coliforms, Enterococci and/or *E.coli*, were recorded at a number of sampling locations for the 2019 sampling event and during previous sampling rounds since 2017. Subsequent testing for bacteroids coordinated by EMPNG returned negative results for all samples. This indicates the faecal coliforms were of non-human origin and were not attributable to EMPNG's sewer system (Tetra Tech Coffey 2021).

Total nitrogen concentrations were elevated above ESMP criteria at several sites, particularly MW-2, located upgradient of LNG Plant facilities therefore unrelated to project activities, GW-21, of which the nitrogen is comprised primarily of nitrate, and GW-22, which was comprised mostly of ammonia.

No hydrocarbon or phenol concentrations above ESMP criteria were detected in the LNG Plant or landfill area, nor are there any indicators of natural attenuation (i.e., biodegradation) processes occurring through the evaluation of geochemical markers for these substances.

7.1.4.4 Groundwater use

Groundwater bores and dug pits are typically used by local villages to the north and south of the LNG Plant site for potable use (most likely accessing freshwater lenses overlying deeper more saline groundwater) (Appendix H Groundwater Baseline).

EMPNG is not permitted to extract groundwater at the LNG Plant for potable use under Environment Permit EP-L3(210).

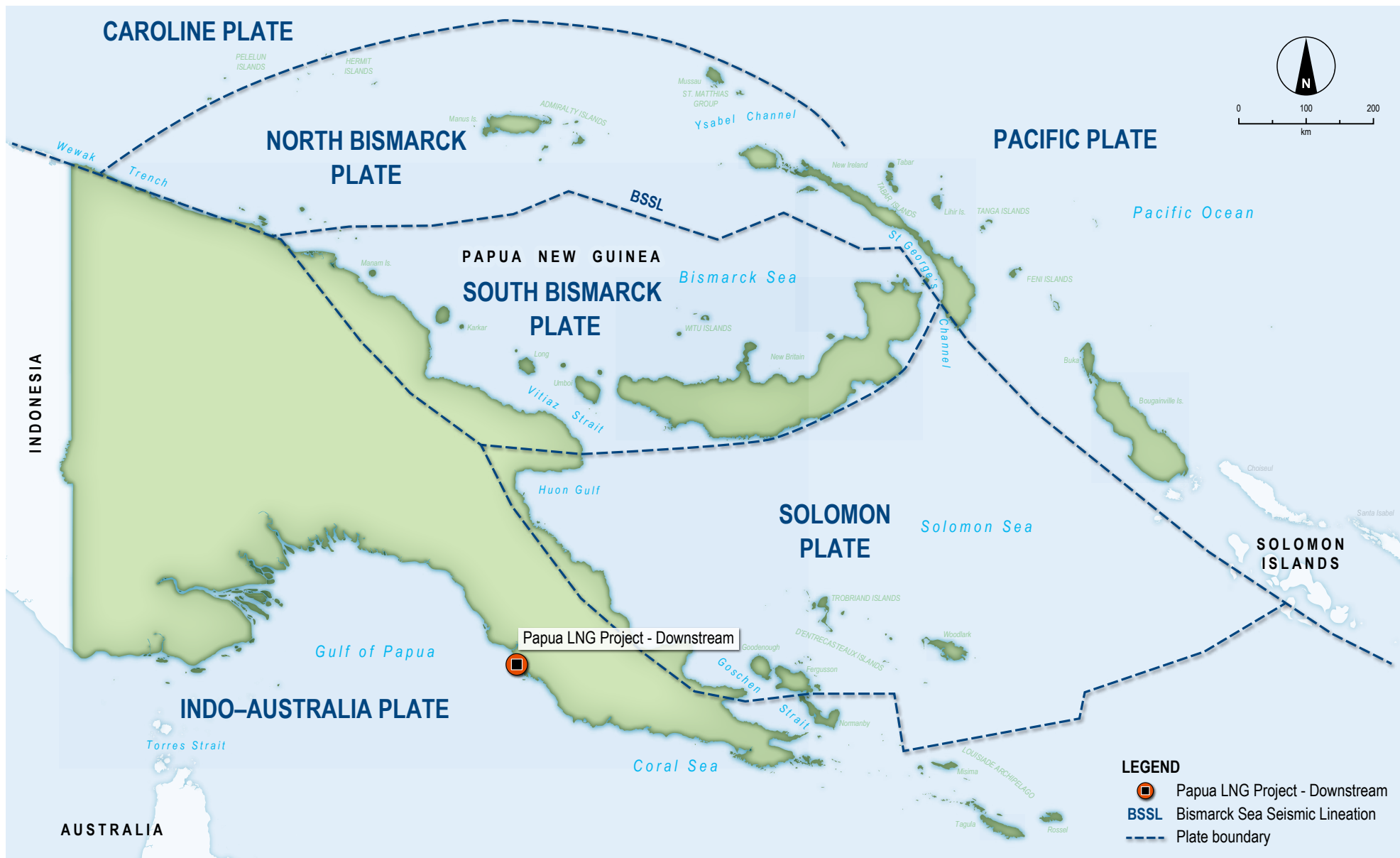
There are limited and sometimes conflicting reports of productive uses of groundwater offsite such as stock, domestic, irrigation or industrial use. Extractive groundwater use has been conservatively adopted as an environmental value for groundwater.

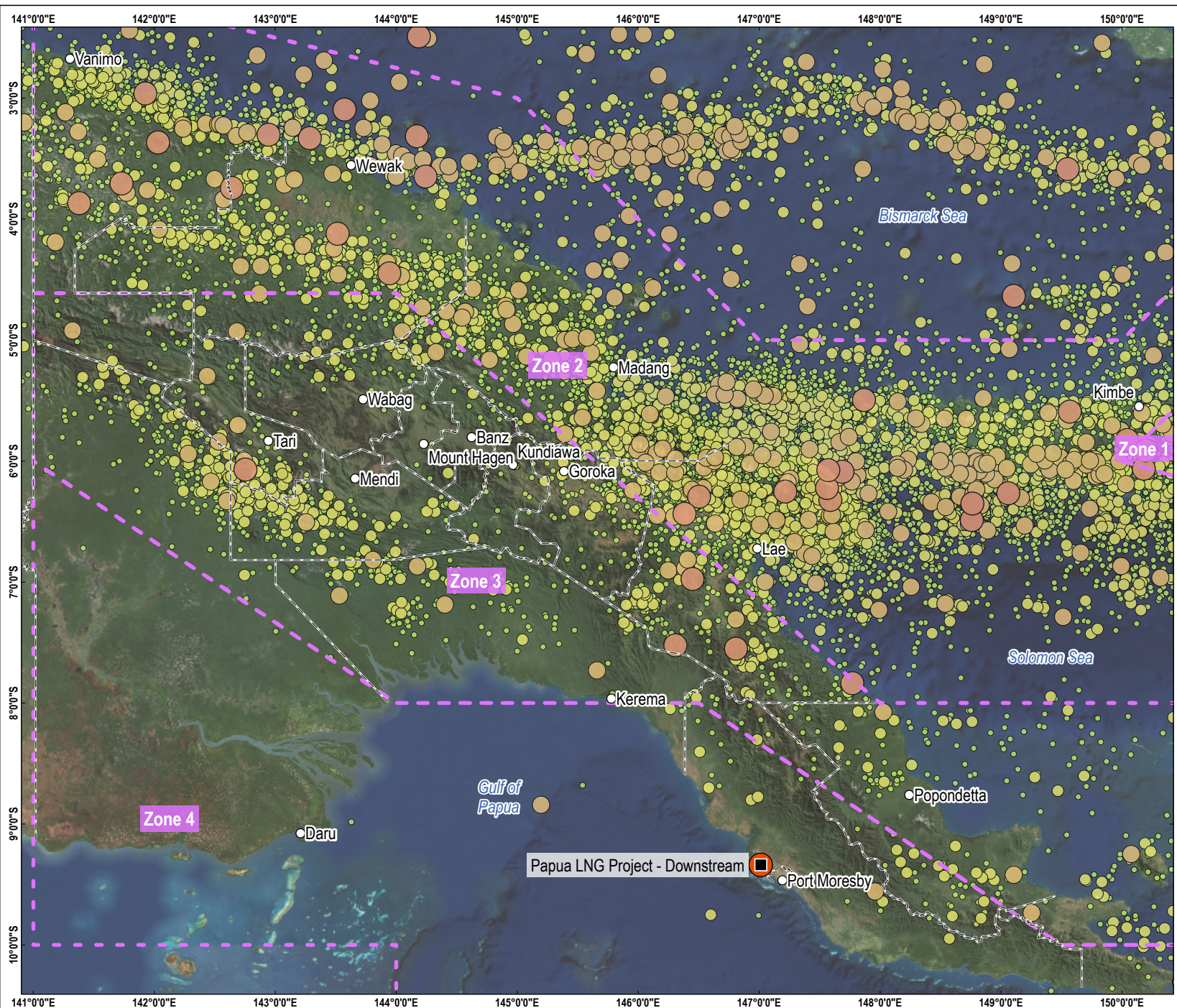
7.1.5 Seismicity

Figure 7.5 shows the tectonic plates and major fault lines of Papua New Guinea. The LNG Plant is in the northern portion of the tectonic Indo Australian tectonic plate. The seismicity of the Project area is classified as Zone 4, which is the least seismically active classification under the Papua New Guinea building standards (PNGBS 1982). Figure 7.6 shows the location of all earthquakes recorded in Papua New Guinea from 1900 to 2022. There is no record of earthquakes in the vicinity of the LNG Plant, with most seismic activity located along the northern coast of Papua New Guinea.

7.1.6 Climate

The longest ongoing climate monitoring records near Caution Bay are collected from meteorological monitoring stations located in Port Moresby, approximately 20 km from the LNG Plant (Coffey Natural Systems 2009; WMO 2023). An automatic weather station (AWS) was deployed on coastal land in Caution Bay in February 2008 during work undertaken for the PNG LNG Project EIS.





LEGEND

-  Papua LNG Project - Downstream
 Province capital
 Province boundary

Seismic activity

Earthquake by magnitude

- | | |
|---|---------|
|  | <5 |
|  | 5 - 5.9 |
|  | 6 - 6.9 |
|  | >7 |

- Seismic zone for building construction in PNG (1 = most unstable)

SOURCE

Earthquake data (1900-2022) from USGS.
Seismic zones from PNGS (1982).
Infrastructure data from EMPNGA and Tetra Tech Coffey
(indicative only).
Place names from NGIA.
Provinces from NSO.
Imagery from ArcGIS Online.



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PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 7.6

Earthquakes in the vicinity of Papua New Guinea (1900 to 2022)



DATE: 04.07.23 PROJECT: 754-MELEN300733 FILE: 300733_02_F07.06_GIS

A weather station has also operated at the LNG Plant since 2014, with weather readings taken at various intervals since the LNG Plant was constructed. The climate in Port Moresby is representative of climate conditions at the LNG Plant.

The Port Moresby-Caution Bay climate regime is classified as Tropical Savanna (Köppen classification: Aw) under the international Köppen-Geiger system (Gillison 1983; Peel et al. 2007). Tropical Savanna is defined by a combination of elevated temperatures and a high annual rainfall with pronounced seasonality. This regime contrasts with the dominant climate regime of Tropical Rainforest (Köppen classification: Af) across the broader region of New Guinea. The seasonality in wind direction, temperature, humidity, and rainfall are broadly controlled by two seasons, between which brief transitional phases occur, namely:

- The north-west monsoonal 'wet season' (known locally as 'lahara') that occurs between the austral summer of December and March, and is associated with warm, humid conditions and frequent rainfall.
- The south-east monsoonal 'dry season' (known locally as 'laurabada') that occurs between June and October, characterised by cooler and drier conditions associated with the south-east trade winds.
- The 'doldrums', typified by more changeable weather that occur during the transitional months of May and November.

El Niño events result in cooler dry and wet seasons than normal in the Port Moresby-Caution Bay area, and lower seasonal sea level and tidal reach. During La Niña events, only the dry season is warmer and both seasonal sea level and tidal reach are higher (Richards et al 2016).

Topographic factors also play a role in determining local weather patterns at various scales along southern Papua New Guinea, and the Owen Stanley Range that forms the backdrop to Caution Bay results in a climate that, while still seasonal, is not subject to the dry season moisture deficit that characterises the adjacent coast (Richards et al. 2016).

Where possible, site-specific data from the weather station has been used to complete the climate sections below. Additional information regarding climate is provided in Appendix E Nearshore Marine Baseline.

7.1.6.1 Rainfall and humidity

Average annual rainfall measured at Port Moresby is 1,012 mm, making it one of the driest localities in PNG (Richards et al. 2016). This reflects the area's dry sub-humid classification of 1,000 to 1,500 mm per year (McAlpine et. al. 1983).

Table 7.2 provides the mean monthly rainfall recorded by the AWS located at the LNG Plant. The mean annual rainfall over the site-specific data record is less than 1,000 mm, slightly less than the mean annual average for the Port Moresby region.

Table 7.2 Mean rainfall statistics for LNG Plant 2015 to 2020

mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean rainfall	298	106	217	52	61	14	12	27	17	22	39	88

Source: EMPNG (2020).

Mean monthly rainfall is generally highest from December/January to March during the wet season. On average, about 80% of rainfall occurs within this period. Humidity generally ranges between 49% and 84% throughout the day most of the year. The highest monthly humidity percentages were recorded during January through to March.

7.1.6.2 Air temperature

Richards et al. (2016) report daily mean minimum and maximum monthly air temperatures at Port Moresby reaching peak monthly averages of 24°C and 32°C respectively in December and January, and low monthly averages of 23°C and 28°C respectively in July and August. The recorded daytime minimum and maximum for 40 years of records were 18°C to 36°C respectively.

Table 7.3 provides each month's average minimum and maximum daily temperatures at the LNG Plant for 2020. Review of the 2021 and 2022 data found errors (i.e., missing data) and therefore were not used in the report.

Table 7.3 Mean air temperature for LNG Plant 2020

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average daily max.	33.0	33.7	33.3	31.4	31.6	30.9	30.3	31.1	31.8	31.4	32.1	31.5
Average daily min.	23.1	23.2	22.6	21.5	22.1	23.8	23.1	20.6	23.7	22.8	21.2	23.7

Source: EMPNG 2020.

The coolest month for the 2020 calendar year was August when the mean daily maximum and minimum were approximately 31°C and 21°C, respectively. The warmest month was February when the mean daily maximum and minimum were approximately 34°C and 23°C, respectively.

7.1.6.3 Evaporation

Annual average evaporation in the Port Moresby area is more than 2,000 mm/year indicating a significant rainfall deficit (REM 2009). This is higher than other recorded sites in Papua New Guinea where estimates range from low to mid 1,000 mm. The data provided in Table 7.4 indicates that evaporation is highest during November, December, and January.

Table 7.4 Mean monthly evaporation recorded at Port Moresby

mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean evaporation	170	139	144	120	117	110	121	131	140	162	178	184

Source: McAlpine et al. 1975.

7.1.6.4 Wind

The wind regime of the Gulf of Papua is tied to the seasonal cycles associated with the northwest monsoon 'wet season', and the southeast trade winds 'dry season' (Hasegawa et al. 2010). Martin et al (2008) describe the wet season wind regime as entailing offshore winds with typical speeds below 5 m/s, and the dry season wind regime being characterised by increased wind energy that more frequently blows onshore at speeds greater than 5 m/s. Data from NSR (1990), Woolfe et al. (1997), and Richards et al. (2016) similarly indicate that:

- During the wet season, winds predominantly blow from the northwest or west at speeds of generally less than 31 kilometres per hour (km/h, 17 knots), with wind speeds exceeding this only 15% of the time.
- During the dry season, windier conditions prevail, with winds travelling distances in the order of 1,000 km across the Coral Sea and Gulf of Papua and exceeding 31 km per hour for 30% of the time.

As part of the PNG LNG Project, three years of offshore Mesoscale Limited Area Prediction System (MesoLAPS) wind data and the wind data collected from the AWS near Caution Bay were analysed. The results are summarised in Table 7.5. The results identified three main features of the ambient wind conditions in Caution Bay (Coffey Natural Systems 2009):

- The dominance of the south-east trade winds offshore
- The existence of katabatic winds (winds that carry higher-density air from elevated areas down a slope via gravity) from the north-east off the coastal topography
- The difference in the wind regime between onshore and offshore sites.

Table 7.5 Summary of the analysis of MesoLAPS and AWS data

Parameter	3 years of MesoLAPS data (July 2005 to July 2008)	3 months of AWS Data (February 2008 to April 2008)
Mean hourly wind direction	4.8 m/s (17.3 km/h)	3.1 m/s (11.2 km/h)
Mean wind direction	300 degrees	85 degrees
Average of Top 100 wind speeds	11.5 m/s (41.4 km/h)	8.8 m/s (31.7 km/h)
Average direction of Top 100 wind speeds	314 degrees	134 degrees

Source: Coffey Natural Systems (2009).

Strong wind speeds are rarely destructive and tropical cyclones with surface winds of greater than 62 km/h rarely occur (McAlpine et al. 1983). Richards et al. (2016) noted that only three cyclones tracked within 100 km of Caution Bay between 1970 and 2010.

7.1.7 Surface water

The physical characteristics of the surface water environment in the Project area and surrounds are described in this section and are primarily based on studies undertaken as part of the PNG LNG Project EIS, and data subsequently collected as a part of the ESMP and Environment Permit conditions for the PNG LNG Project.

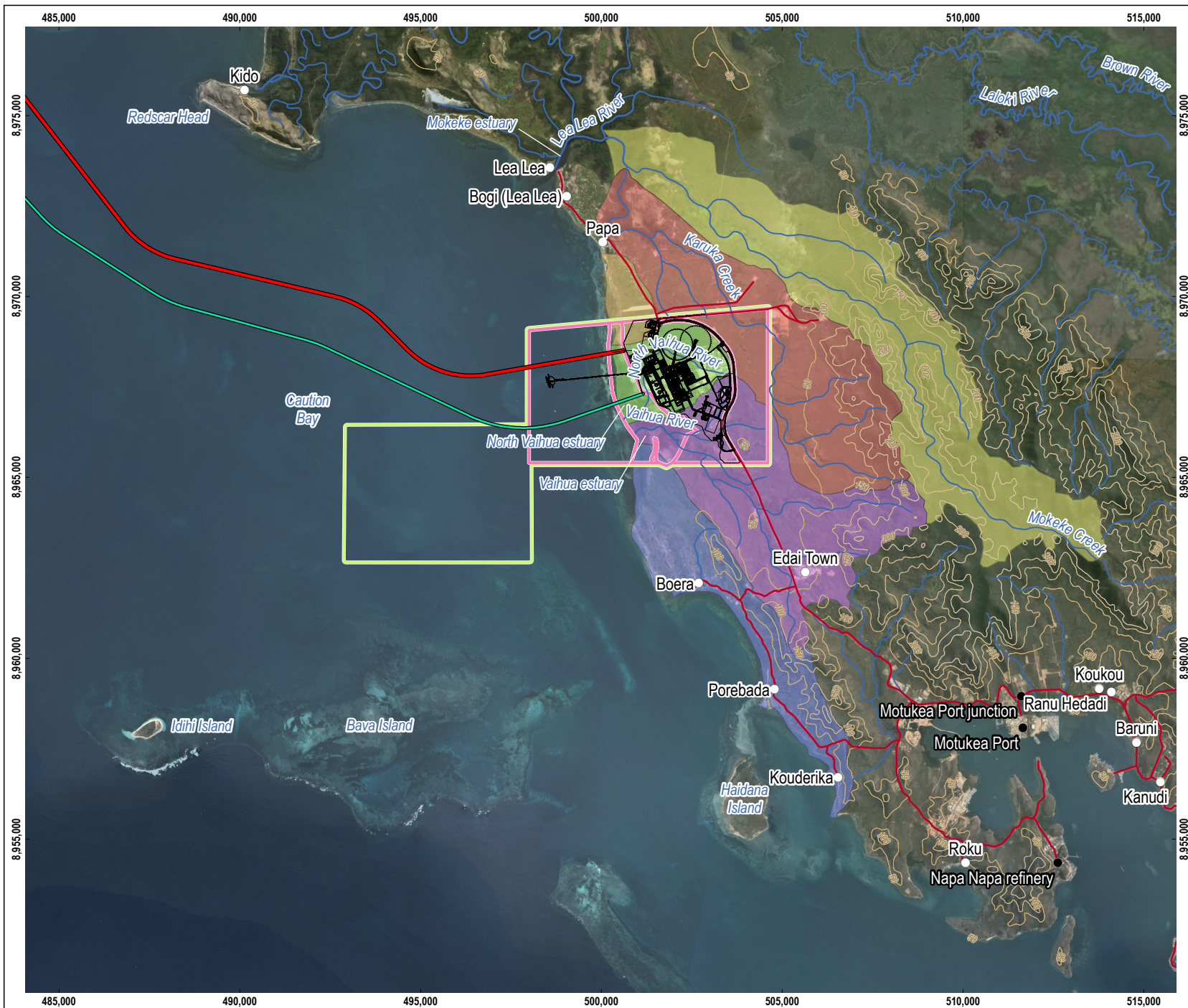
The LNG Plant area is located across three main catchments including the Vaihua River, the North Vaihua River and the Karuka Creek, and a minor coastal catchment as shown in Figure 7.7. The characteristics of the three main catchments are described below.

7.1.7.1 Vaihua River

A small portion of the LNG Plant is located within the Vaihua River catchment, a 1,950 hectare (ha) coastal catchment. The river drains into the Vaihua River estuary to Caution Bay.

The lowest or intermittent flows in the Vaihua River occur during the dry season between May and October and the highest flows occur between December and March in the wet monsoon season. Moderate flows occur during the transitional months of November and April. In the mid to upper Vaihua River catchment during the dry season, intermittent flows in the main channel leave remnant and isolated pools of standing water. The majority of tributaries of the Vaihua River are ephemeral and flow for short periods only following rainfall (McAlpine et al. 1983). The high clay content of soils in the catchment result in high rainfall runoff rates and stream flows that rise and fall rapidly. Tributary streams typically have small cross-sectional areas that cannot support larger flows, and frequent overbank flooding of the floodplain occurs.

Natural erosion of streambed sediments and soils is sporadic and occurs only during infrequent flood flows. Most bed sediment material comes from upstream river reaches (Coffey Natural Systems 2008); however, riverbank erosion as a result of streamflow has led to minor localised sediment inputs to the river's main channel in the mid and lower reaches.



LEGEND

- Village
- Point of interest
- Road
- Watercourse
- Contour (50 m interval)
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Existing and proposed plant layout
- PPFL2 boundary
- APPF boundary
- Catchment area
 - Karuka Creek catchment
 - Moreke Creek catchment
 - North Vahua River catchment
 - Vahua River catchment
 - Minor coastal catchment
 - Series of minor coastal catchments

SOURCE
 Catchments, contours, infrastructure, roads, watercourses and lease boundary from EMPNGA.
 Imagery from ArcGIS Online and Planet Labs.



0 1 2 3 km
SCALE 1:150,000
 PAGE SIZE: A4
 PROJECTION: WGS 1984 UTM Zone 55S

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FIGURE 7.7

Catchments at the LNG Plant and surrounds



DATE: 04.07.23 PROJECT: 754-MELN300733 FILE: 300733_02_F07.07_GIS

The catchment upstream of the Vaihua River has three geomorphic units:

- **Upper reaches** – the Vaihua River upper reaches are a partly confined system within low hill terrain. Flows in this reach are higher energy due to the confined nature of the river due to steep valley sides and a greater channel slope (greater than 3°). Finer sediment fractions are washed downstream during high flows and stormflows in the upper catchment stream leaving coarser substrate (i.e., cobbles and boulders) in the main channels. The streambanks are comprised of bedrock and highly stable. Dense riparian vegetation also contributes to stability of the system.
- **Undulating landscape channels** – this reach of the river comprises a meandering channel with lower gradients (1 to 2°) within undulating lowlands. In some locations, the river channel is influenced by the surrounding terrain (upstream reaches of the Vaihua River). The riverbanks are lower and more stable, and the channel is narrower, similar to a floodplain system. The riverbed predominantly comprises of coarse gravel with some eroding material upstream.
- **Floodplain channels** – this river reach is characterised by a meandering system flowing through a flat alluvial floodplain (Gilgai country), composed of cracking clays and poor drainage. The Vaihua River and its tributaries are generally incised with a high potential for overbank flow. The main channel banks are typically composed of material with high clay content and channel gradients are low (less than 1°). Riverbed sediments are composed of mainly sand and gravel, ranging from clayey sands, clayey gravels and silty sands. The system is low-energy with a low potential for sediment transport. Riparian vegetation is intermittent along some riverbanks, contributing little bank stabilisation. In other areas, some stability is provided by pasture grasses encroaching on the riverbanks.

7.1.7.2 North Vaihua River

Most of the LNG Plant is located within the small North Vaihua River catchment (Figure 7.7). The North Vaihua River drains into the North Vaihua River estuary within a small 550 ha coastal catchment.

Flows in the North Vaihua River and its tributaries are intermittent, with flow occurring immediately after rainfall. Watercourses in the catchment are ephemeral and there is a distinctive landscape of dry watercourses and drainage lines. Some drainage lines are not distinct, and sheet flow through the grasslands takes place during rainfall. Floodplain inundation occurs during the wet season from December to March, which recharge the backwater systems, such as mudflats and the coastal and riverine mangroves.

The upper reaches of the North Vaihua River estuary are comprised of clay mudflats with wide but shallow distributary channels that are intermittently inundated during high tides and high rainfall events.

Channel gradients are shallow (less than 2°), and channel width is narrower than the Vaihua River. Channel bed sediments consist of silts and clays from the banks, and sands and gravels from upstream river reaches. The banks are generally stable and supported by dense grasses, with the exception of the lower banks.

7.1.7.3 Karuka Creek

The catchment of Karuka Creek is 2,325 ha and drains to Mokeke Creek, about 1 km upstream from the Mokeke Creek estuary (Figure 7.7). Lea Lea Road is located within the Karuka Creek catchment.

Karuka Creek is a meandering system that flows within an irregular narrow valley and has low slope gradients (less than 2°) in all reaches, except the eastern tributary headwaters. The creek only has a narrow floodplain throughout the catchment and is more confined than the Vaihua and North Vaihua river catchments. Karuka Creek tributaries are ephemeral, flowing intermittently following rainfall. The tributaries of this system to the east are higher energy, based on the steeper catchments of the north-northwest to south-southeast trending ranges east of the LNG Plant site. The western tributaries drain small gradually sloping catchments. The bed sediments of the eastern tributaries consist of cobbles or gravels, and those of the western tributaries comprise clays and silts. The Karuka Creek catchment watercourse have stable banks and are composed of

consolidated sediments with high silt and clay content (Coffey Natural Systems, 2009), except for reaches where the banks contain old bed material.

7.1.7.4 Water quality

Water quality monitoring was conducted as part of the PNG LNG Project EIS baseline sampling. Dissolved metal concentrations were compared with two guidelines: Schedule 1 of the Environment (Water Quality Criteria) Regulation 2002 and the Australian and New Zealand Guideline for Fresh and Marine Water Quality (ANZG 2018).

Results were indicative of agricultural activity and human activity, with some exceedances of guidelines. Dissolved metals that exceeded one or more of the guideline values for freshwater included cadmium (VAI6 and KAR4), copper (VAI6) and lead (VAI6). These freshwater sampling sites are located upstream of the LNG Plant site. Only boron exceeded the PNG (Water Quality Criteria) Regulation guideline value of 2 mg/L for estuarine sites VAI1, VAI2, VAI3, VAI4, KAR1 and KAR2. The source of the exceedances is unknown, however, are expected to be related to natural baseline variability in freshwater environments.

A review of water quality data provided by EMPNG for monitoring undertaken between 2017 and 2021 was conducted. Water quality data for Vaihua and North Vaihua rivers were limited to field physical parameters and nutrients. One sampling event for site VAI3 (27 October 2017) included dissolved metals. The results for all dissolved metals were within the guideline values.

EMPNG has undertaken routine monitoring of process water from the LNG Plant as well as at the Vaihua River (within the estuarine zone) and stormwater channels within the LNG Plant from 2014 to 2021.

This is in accordance with a water quality monitoring program to confirm that project site discharges comply with water quality goals and the requirements of the Environment Permit for the PNG LNG Project. The physical parameters were within the discharge limits outlined in the Environmental Permit; however, faecal coliform measurements were found to be above the Environment Permit criteria limit of no more than 200 MPN / 100 mL both spatially and temporally across the site including: Mixing Pit (LNGP-S3) between 2016 and 2018; process area retention pond (LNGP-RP-1) between 2015 and 2019; and the Unidro waste water treatment plant WWTP (LNGP-W1) between 2016 and 2018.

The Unidro unit was temporarily decommissioned in 2018 and reinstated in 2023, with approval from CEPA to discharge to a surface irrigation area. The Toray WWTP was originally commissioned as a standby unit and has operated since 2017. The unit recorded only four faecal coliform excursions out of 63 sampling events between 2017 and 2021. Monitoring results for the tidal flats recorded 24 faecal coliform excursions from 28 sampling events between 2017 and 2019. The Vaihua River recorded 26 excursions out of 31 monitoring events between 2017 and 2021.

Between April and May 2018, EMPNG conducted a month-long faecal coliform study to identify potential point source(s) contributing to the high coliform results at the process area retention pond, mixing pit and the tidal flats, including other suspected discharges and run-offs from facilities. The study concluded that the high faecal results recorded at these three monitoring locations were not from human origin. In November 2019, CEPA provided an approval letter to EMPNG to cease further faecal coliform and other bacteria (*E. Coli*,) monitoring at the LNG Plant process area retention pond, mixing pit and the tidal flats.

7.1.7.5 Stream bed sediment quality

Stream bed sediment samples were analysed for metals concentrations as part of the 2008 survey and compared below with default guideline values for toxicants in sediment (ANZG 2018). Default guideline values (DGV) indicate the concentration below which there is a low risk of unacceptable effects occurring, and the upper guideline value (GV-High) provides an indication of concentrations at which toxicity-related adverse effects may already be observed (ANZG 2018). Results are:

- Arsenic concentrations within the North Vaihua River estuary (saltwater) exceeded the DGV guideline but not the GV-High guideline.
- Nickel concentrations at all sites except one in the North Vaihua River estuary exceeded the DGV guideline but did not exceed the GV-High guideline.
- Nickel concentrations at one site within Karuka Creek (freshwater) and one site within the Vaihua River (freshwater) exceeded the DGV guideline as well as the GV-High guideline.
- Silver concentrations at all sites were below the GV-High guideline value; however, determination of compliance with the DGV was not possible due to detection limits being too high.

These exceedances are expected to be related to natural baseline variability in freshwater environments.

7.1.7.6 Flood risk

A flood assessment for the LNG Plant was undertaken in 2013 and was updated in 2023 (Appendix I Flood Assessment). The study characterised baseline flood conditions at the LNG Plant site (existing facilities) and nearby sensitive receptors using existing data and assessed the movement of surface waters into and through the LNG Plant site (and surrounding area) to quantify hazards from flooding of the site, including consideration of high tides and storm surges.

The assessment showed two main flood flow paths that passed through the site (Figure 7.8). The 'southern stream' catchment extended south of the LNG Plant with the stream discharging to the sea south of the site. The Australian Rainfall and Runoff 2016 flood hazard categories were used to assess the results (Appendix I Flood Assessment).

Flood modelling indicated that:

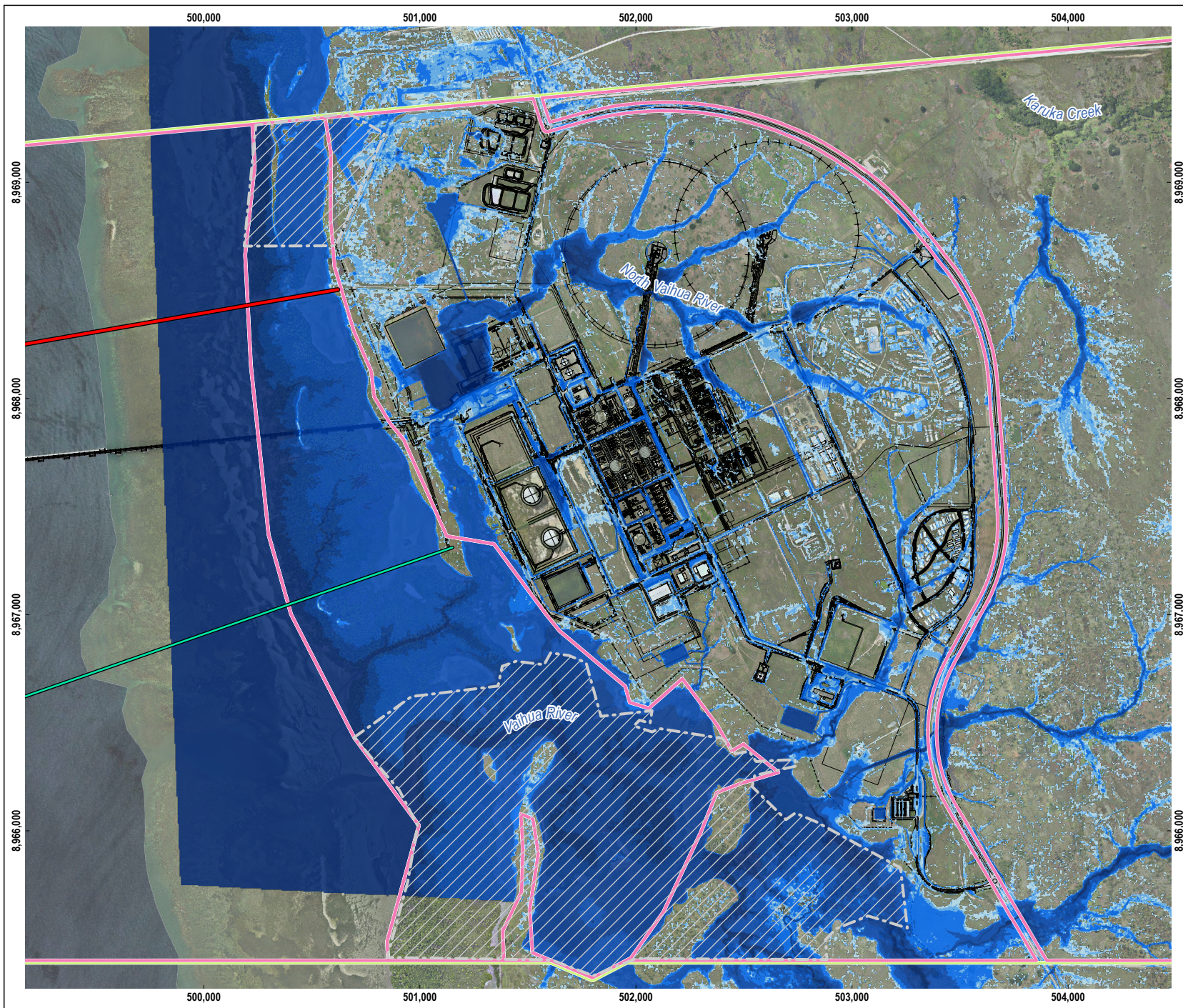
- During both the 1% and 10% Annual Exceedance Probability (AEP) event the proposed infrastructure is likely to have little impact on the existing flow regime. Proposed infrastructure located within the existing flood extents include the condensate tanks and proposed roads.
- Flow velocities in vicinity of the proposed infrastructure are negligible (<2 m/s) and as such erosion protection is not required.
- Five areas are prone to hazardous flooding, based on flood depths and velocities. These five areas are:
 - Immediately north and west of condensate tanks
 - West of the existing flare stack and north of the naphtha tanks
 - At the existing flare stack
 - At the proposed new flare stack
 - At the western margin of the camp.

The findings of the flood assessment will be considered in the detailed design for the Project.

7.1.8 Air quality

This section, based on air quality and plume rise assessments completed by SLR in Appendix J Air Quality Assessment, presents baseline air quality for the Project, which considers existing air pollution sources at the LNG Plant and surrounds. Air quality monitoring data was collected during 2015 and 2016 for approximately 12 months at Gate 1, Gate 2 and Gate 3 locations shown in Figure 7.9 (with locations of previous air quality monitoring sites) and is representative for the operating LNG Plant.

Ambient air quality criteria adopted for the air quality baseline assessment including those from the LNG Plant's Environment Permit (EP-L3(210)), are shown in Table 7.6.



- LEGEND**
- PNG LNG pipeline
 - Proposed Papua LNG pipelines route
 - Existing and proposed plant layout
 - PPFL2 boundary
 - APPFL boundary
 - Cultural heritage restricted area

- Flood depth (m)**
- > 1.5
 - 1.0 - 1.5
 - 0.5 - 1.0
 - 0.2 - 0.5
 - 0.1 - 0.2
 - < 0.1

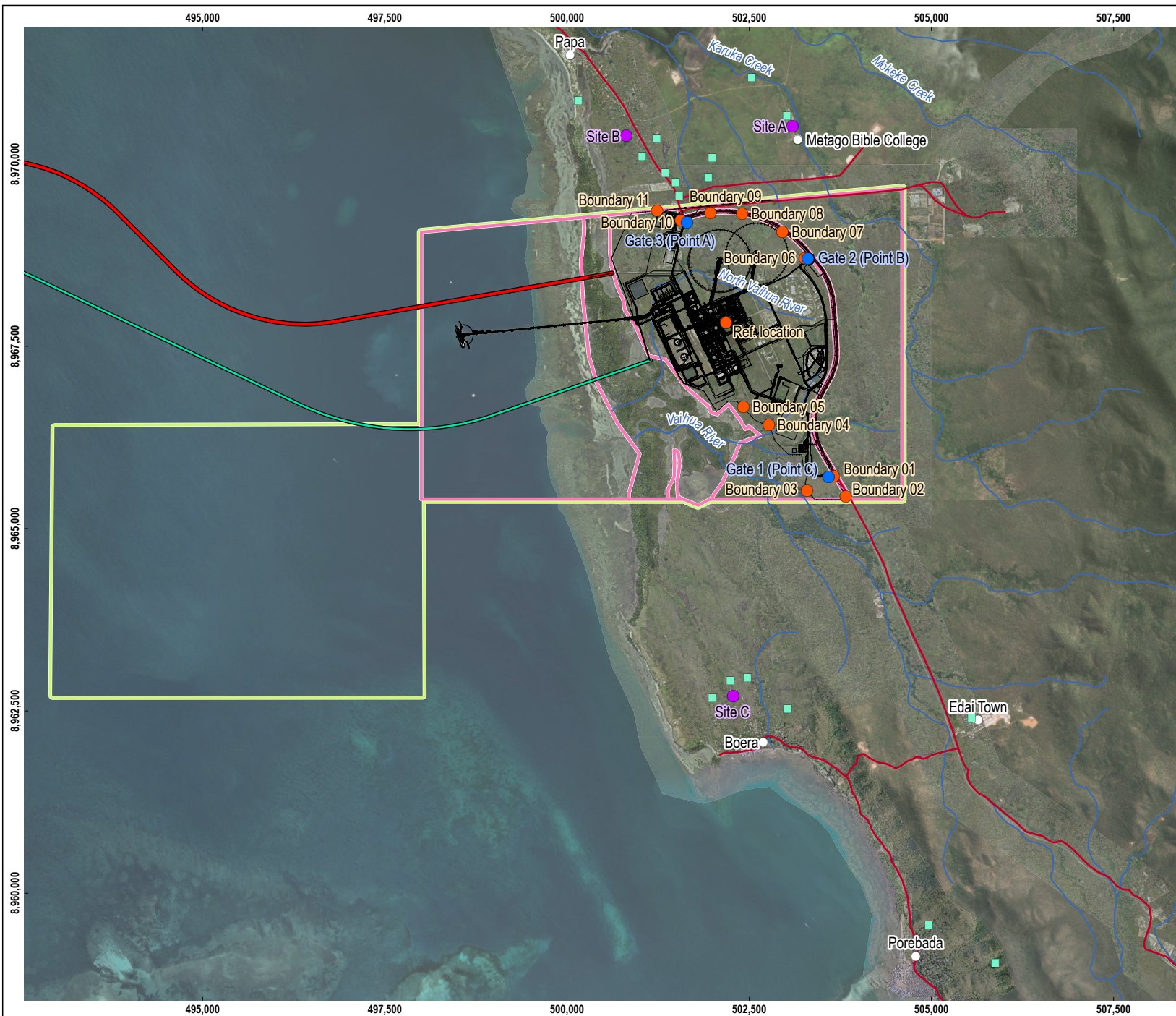
SOURCE
 Flood model from Water Tech.
 Infrastructure, cultural heritage and lease boundary from EMPNGA.
 Imagery from EMPNGA and Google Earth.

0 500 m
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 PROJECTION: WGS 1984 UTM Zone 55S

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FIGURE 7.8
 1% AEP existing flood depth





LEGEND

- Village
- Air and noise sensitive receptor
- Air and noise monitoring location (2008)
- Air quality monitoring location (2019)
- Noise monitoring location (2019)
- Road
- Watercourse
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary

SOURCE

Monitoring locations, infrastructure, roads, watercourses and lease boundary from EMPNGA. Imagery from ArcGIS Online and Planet Labs.



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 SCALE 1:75,000
 PAGE SIZE: A4
 PROJECTION: WGS 1984 UTM Zone 55S

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FIGURE 7.9

Air and noise monitoring locations and sensitive receptors



Table 7.6 Ambient air quality criteria used in the baseline assessment

Pollutants	Averaging time	Criterion ($\mu\text{g}/\text{m}^3$)	Source
Nitrogen dioxide (NO_2)	1-hour	200	Environment Permit EP-L3(210), WHO 2021
	24-hours	25	WHO 2021
	Annual	40	Environment Permit (EP-L3(210))
		10	WHO 2021
Sulphur dioxide (SO_2)	10-Minutes	500	Environment Permit EP-L3(210), WHO 2021
	1-hour	200	US EPA 2010
	24-hours	20	Environment Permit (EP-L3(210))
		40	WHO 2021
Carbon monoxide (CO)	1-hour	35,000	WHO 2021
		30,000	ESMP (PNG LNG 2019)
	8-hours	10,000	WHO 2021, ESMP (PNG LNG 2019)
Benzene	Annual	5.0	EC 2022, current
		3.4	EC 2022, proposed
Total suspended particulate (TSP)	24-hours	150 to 230	ESMP (PNG LNG 2019)
	Annual	60 to 90	ESMP (PNG LNG 2019)
PM_{10}	24-hours	45	WHO 2021
	Annual	15	WHO 2021
$\text{PM}_{2.5}$	24-hours	15	WHO 2021
	Annual	5	WHO 2021

7.1.8.1 Existing air quality

The LNG Plant operations were found to be the main source of pollution within the Project area, with two other notable sources of existing and future air emissions: the NiuPower 50-megawatt (MW) gas-fired power station located approximately 4 km to the north-east of the site and Dirio gas-fired 47 MW power station 300 m east of the NiuEnergy power station.

Other potential sources of air emissions (particles, NO_x , SO_2 and hydrocarbons) in the area include domestic and agricultural activities, as well as road traffic, in the villages surrounding the LNG Plant including Lea Lea, Papa, Boera and Porebada. Other sources of particulate matter, such as sea salt and smoke from local and remote fires, are also present intermittently.

Existing air quality results relative to Gate 1, Gate 2 and Gate 3 are summarised as:

- The ambient 24-hour average total suspended particles (TSP) concentrations measured were below the adopted guideline level of $150 \mu\text{g}/\text{m}^3$, except for elevated TSP concentrations reported at Gate 3 during the November sampling period. This was due to a temporary, localised source. The annual average TSP concentration recorded across all three monitoring sites was $20.2 \mu\text{g}/\text{m}^3$, which is well below the adopted criteria of $60 \mu\text{g}/\text{m}^3$.
- The 24-hour average concentration of PM_{10} was below the adopted guideline value of $50 \mu\text{g}/\text{m}^3$, except for three occurrences where the recorded 24-hour average exceeded the guideline (up to $58 \mu\text{g}/\text{m}^3$); one

at Gate 1 and two at Gate 3. The annual average concentration of PM₁₀ (17.6 µg/m³) was below the adopted guideline value of 20 µg/m³.

- The 24-hour average PM_{2.5} concentrations were below the adopted WHO guideline value of 25 µg/m³ with the exception of four exceedances at all sites in December 2015, with a maximum of 30 µg/m³. The annual average concentration across the three monitoring sites was 7.3 µg/m³, which is below the adopted guideline value of 10 µg/m³.
- The nitrogen dioxide levels at all sites were reported at less than 8 µg/m³, with an average concentration over the year of 4.2 µg/m³. This was below the adopted annual average criteria of 40 µg/m³.
- All sulphur dioxide concentrations were less than 20 µg/m³ with the annual average for all three sites 4.7 µg/m³. This is below the Environment Permit average standard of 20 µg/m³.
- Recorded 1-hour average carbon monoxide levels at all three sites were less than 1 µg/m³, which was well below the adopted guideline value of 30,000 µg/m³.
- Ozone, a secondary pollutant formed on warm summer days by the influence of solar radiation on a mixture of airborne pollutants (ozone precursors) was elevated (compared to US EPA National Ambient Air Quality Standards (137 µg/m³) at approximately 171 µg/m³ for the two-week maximum over the monitoring period, and the average concentration recorded over the year across all three monitoring sites was 102 µg/m³. These concentrations, however, are characteristic of the background air environment, not due to emissions from the LNG Plant.

7.1.8.2 Sensitive receptors

The four closest villages to the LNG Plant are Lea Lea, Papa, Boera and Porebada which are located in the Hiri Rural Local Level Government area with a total population of approximately 47,000 people. The populations of these villages are:

- Papa: 2,415 people
- Boera: 3,178 people
- Porebada: 7,193 people
- Lea Lea: 4,577 people.

Four residences identified within 500 m from the northern boundary of the LNG Plant site and thirteen representative receptor locations for the villages were selected to use in the air dispersion modelling study to represent the residential areas closest to the Project as shown in Figure 7.9.

7.1.9 Noise

The existing noise environment was characterised based on the noise baseline assessment conducted for the Project by SLR Consulting (Appendix G Noise Impact Assessment).

Unattended noise monitoring was undertaken at sensitive receptors close to the LNG Plant between 13 and 16 May 2019 to characterise the existing ambient noise levels (Figure 7.9). The sites selected for monitoring were:

- Metago Bible College located approximately 2.4 km north-northeast of the LNG Plant
- Papa Village located approximately 2.6 km north-northwest of the LNG Plant
- Boera Village located approximately 4.5 km south of the LNG Plant
- Lea Lea Village located approximately 4.5 km north-west of the LNG Plant.

Operator attended daytime measurements were also taken at Edai Village, approximately 5.5 km south-east of the LNG Plant. The sites were selected based on noise level monitoring undertaken in 2008 as part of the PNG LNG Project.

7.1.9.1 Background noise environment

Table 7.7 summarises the average background noise levels for daytime, evening and night-time periods, as well as the LA₉₀ and LA_{eq} noise levels, recorded in 2019 by the unattended noise logger. Based on the measured noise monitoring results and the noise level time traces, noise emitted by the existing normal operation of the LNG Plant was not identified at sensitive receptors during the monitoring period, and the cause of ambient noise levels above the noise limit is due to local noise sources. The results showed that, at all sites, the noise levels during the evening and night are higher than during the day, which was attributed to elevated insect noise, a common feature of the ambient environment throughout Papua New Guinea.

Results from operator-attended baseline noise surveys indicated that the noise sources at all monitoring locations were similar in character, with the main noise sources being of natural origin, such as wind in foliage, insects, birds and people talking. Vehicle movements also accounted for a large portion of noise generation.

Table 7.7 Summary of background noise levels

Average ambient noise level (dBA)							Noise Environment Permit criteria External one hour LAeq (dBA)	
Location	LA ₉₀	LA _{eq}	LA ₉₀	LA _{eq}	LA ₉₀	LA _{eq}	Day (7:00 to 22:00)	Night (22:00 to 7:00)
	Day (7:00 to 18:00)		Evening (18:00 to 20:00)		Night (22:00 to 7:00)			
Metago	32	47	42	54	40	44	55	45
Papa	36	50	43	53	46	52		
Boera	33	50	42	52	46	49		
Lea Lea	37	50	42	50	41	44		

Bold values indicate exceedances of noise permit criteria.

Source: Appendix G Noise Impact Assessment.

7.1.9.2 Sensitive receptors

The sensitive receptors for noise are the same as those described for air quality in Section 7.1.8.2. An additional thirteen representative receptor locations for the villages Papa, Boera, Porebada and Lea Lea were selected to use in the noise modelling study to represent the residential areas closest to the LNG Plant.

7.2 TERRESTRIAL BIOLOGICAL ENVIRONMENT

The terrestrial biological environment includes the characteristics, vegetation communities, ecosystems and flora and fauna species that contribute to terrestrial biodiversity. This section summarises the findings of the biodiversity surveys undertaken as part of the PNG LNG Project in 2008, the LNG Plant pre-construction survey in 2009, and a weeds and wallabies survey carried out in 2019 within the LNG Plant site.

The study area for the field survey completed in 2008 comprised a 4,450 ha area shown in Figure 7.10 (Woxvold 2008). The surveys were conducted along walking trails and by driving around the LNG Plant site and included birds, reptiles, amphibians and non-volant (non-flying) mammals. Small Elliot traps along the Beach Track and South Track transects were set to survey small mammals. Additionally, local interviews were conducted wherein landowners were asked about mammals they had seen or hunted in the area. A supplementary list of species that could occur was compiled from published information.

Annual weed audits were conducted between 2013 and 2016 as part of EMPNG ongoing monitoring program (Biotropica Australia 2016). Additional field surveys focusing on weeds and wallabies were conducted in July

2019 within the LNG Plant site boundary fenceline for the Project by Ecomate Pty Ltd and Tetra Tech Coffey (Appendix K LNG Plant Weed Survey). The study aims were to determine the presence or absence of weed species in accordance with the EMPNG invasive species register that would require management, and to estimate wallaby population size within the LNG Plant site security fence and the proposed laydown area. The weed survey method included visual observations and systematic recording of site data. The wallaby survey method included sightings and headcounts.

7.2.1 Vegetation

Vegetation and habitats of the LNG Plant have been heavily modified by human activities. Much of the site was cleared early in the twentieth century for agriculture. The modified grassland and savanna habitat that is now present across most of the area is contributed to by seasonal fires.

In 2008, habitats in the study area included grassland and open woodland (35%), savanna with small patches of gallery forest (57%), mangroves (6%), subcoastal wetlands/mudflats (2%) and oceans and coastal marine habitats (Figure 7.10).

The area around the LNG Plant comprises primarily *Heteropogon-Dichanthium* grasslands as most of the habitat within the LNG Plant fenceline has been disturbed during construction and operation of the LNG Plant. Plate 7.4 to Plate 7.8 show examples of vegetation and flora in the vicinity of the LNG Plant.

7.2.1.1 Grassland and open woodland

The dominant habitat in the north-west in the LNG Plant area is grassland on alluvial plains. The predominant flora is speargrass (*Heteropogon*) and pasture grass (*Dichanthium*) species native to southern Papua New Guinea. These species have a large exotic component that includes many complex noxious weeds (e.g., *Alysicarpus vaginalis*, *Atylosia scarabaeoides*, *Clitorea ternatea*, *Panicum maximum*, *Passiflora foetida*, *Sida acuta* and *Tridax procumbens*) (Woxvold, 2008).

Various open woodland communities occur across grassland-dominated areas, including alluvial flats areas with scattered trees, areas of introduced rain trees (*Samanea saman*) and Pandanus woodland associated with drainage lines.

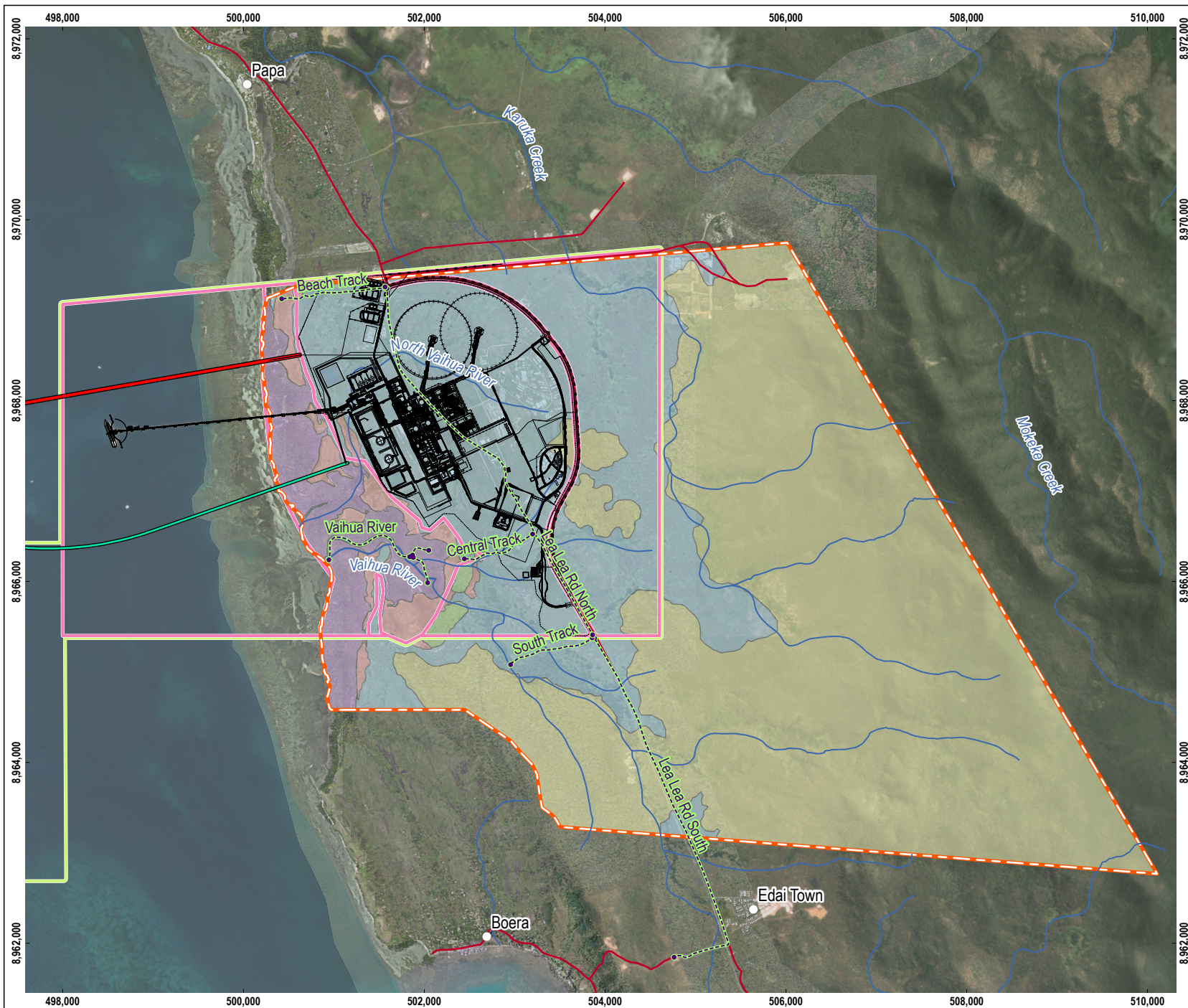
7.2.1.2 Savanna and gallery forest

Savanna, which is characteristic of a long dry season, comprises mainly various eucalypt species and has a grassy understorey with cycads and banksias. Sheltered areas contain patches of gallery forests in some areas (Woxvold 2008).

In the Port Moresby area, Savanna supports many fauna species, several which are found almost exclusively in this habitat. Flora and fauna of Papua New Guinea's savannas are largely of Australian origin and savanna around the LNG Plant was found to be heavily disturbed and expected to support a small portion of those taxa typically found in this habitat throughout the local region.

Exotic species *Heteropogon* and *Dichanthium* communities that characterised the site's grasslands and open woodlands dominated the understorey vegetation. Anthropogenic activities have greatly reduced tree densities, with predominantly *Eucalyptus alba* and *E. confertiflora* present.

Riparian vegetation, such as that along the Vaihua River, often densely overgrown with vines, provides potential habitat for forest fauna that are less tolerant of drier habitats, including a variety of birds of paradise.



LEGEND

- Village
- Fauna survey transect
- Road
- Watercourse
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary
- Terrestrial Biodiversity Study Area

Biodiversity habitat classification

- Grassland/open woodland
- Grassland (rocky)
- Mangrove
- Mudflat/saltflat
- River
- Savanna

SOURCE
 Survey transects, habitat classification, study area, infrastructure and lease boundary from EMPNGA. Imagery from EMPNGA and Planet Labs.

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 PROJECTION: WGS 1984 UTM Zone 55S

EXXONMOBIL PNG ANTELOPE LIMITED
 PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 7.10
 Terrestrial biodiversity study area, habitat classification, and fauna survey transects (2008)



Plate 7.4
Grassland adjacent to LNG Plant site



Photo credit: Tetra Tech Coffey

Plate 7.5
Examples of weeds in the vicinity
of the LNG Plant site



Photo credit: Tetra Tech Coffey

Plate 7.6
Pandanus woodland



Photo credit: Tetra Tech Coffey

Plate 7.7
Riparian forest along the Vaihua River



Photo credit: Coffey Natural Systems, 2008

Plate 7.8
Mangroves and subcoastal wetlands/mudflats
around the Vaihua River



Photo credit: Coffey Natural Systems, 2008

Plate 7.9
Wallaby in the operations Camp area



Photo credit: Tetra Tech Coffey

7.2.1.3 Mangroves and subcoastal mudflats

An integrated system of mangroves and subcoastal mudflats extends along most of the coastline and north towards Papa Village. Southwest of the LNG Plant large blocks of mangroves surround the Vaihua River mouth in contrast to the relatively narrow fringing mangrove areas elsewhere in the area. During the wet season, subcoastal mudflats can be inundated, while in the dry season, large areas of salt flats remain after the mudflats dry up.

Mangroves support a rich biodiversity including mangrove specialist fauna such as reptiles, birds, resident and migratory shorebirds, and other waterfowl. Mangrove habitats regulate hydrology, contaminant levels and system pH, which are important ecosystem functions.

The mangroves and mudflats of the nearshore environment in Caution Bay are further discussed in Chapter 8 Receiving Environment: Marine and Appendix E Nearshore Marine Baseline.

7.2.1.4 Vaihua River Ecosystem Complex

The 2008 study identified the Vaihua River Ecosystem Complex as an important component to the overall biodiversity of the study area, compared to an otherwise highly modified landscape. The Vaihua River Ecosystem Complex has high connectivity within a range of habitat types, including (Woxvold 2008):

- Submerged and intertidal coastal marine reefs and sediments
- The study area's largest intact non-coastal fringing area of mangrove and mudflats
- The coastal approaches of the site's two main watercourses, including Vaihua River
- Rocky ridges with grassland and open woodland (including *Melaleuca*)
- A small inland buffer zone of grassland and open woodland on alluvial flats.

7.2.1.5 Weeds

The weed survey completed in 2019 surveyed weed species within the LNG Plant and the proposed laydown area (Appendix K LNG Plant Weed Survey). All weeds encountered were identified to species level and an assessment made of their site abundance, diversity and range. These were compared with the previous weed audits undertaken between 2013 and 2016 (Biotropica Australia 2016).

The 2019 survey identified 38 weed species within the LNG Plant site. That count increased to 41 weed species when including the proposed laydown area. This is consistent with the previous weed audit conducted in 2016, which identified 37 weed species within the LNG Plant (Table 7.8) (Biotropica Australia 2016). The proposed laydown area was not surveyed in 2016. There were more weed species identified as common (widespread patches of greater than 20 individuals) in 2019 (eight) than in 2016 (five); as well as more occasional weeds (patchy occurrence of 6 to 20 individuals) in 2019 (18) compared to 2016 (11). The 2008 baseline survey identified 74 weed species (36 common, 29 occasional and 9 rare) within the LNG Plant site and the surrounding area, including in the laydown area (Woxvold 2008). Direct comparisons to the 2019 survey are limited because the 2008 survey covered a much broader area than the 2019 survey.

In 2019, less weed infestations were observed around the main buildings where lawns and grounds at the LNG Plant were actively maintained, indicating effective weed management in these areas. Denser weed growth away from natural remnant stands was identified at the outer periphery of the LNG Plant site. These areas were unused, previously cleared of natural vegetation and were close the public access road.

Table 7.8 Weed species occurrence in the LNG Plant site as recorded in 2008, 2016 and 2019

Weed Occurrence	Weed survey LNG Plant, laydown area and surrounds 2008	Weed survey LNG Plant 2016	Weed survey LNG Plant 2019	Weed survey LNG Plant and laydown area 2019
Common species (>20 individuals)	36	5	8	13
Occasional species (<20 individuals)	29	11	18	17
Rare species (≤5 individuals)	9	21	12	11
Total species recorded	74	37	38	41

Source: Appendix K LNG Plant Weed Survey.

Fourteen weed species recorded within the LNG Plant site in the 2019 survey were not recorded in the 2016 survey. Most of these species were Priority 3 (seven) and Priority 2 (five) weeds, with two Priority 1 species (*Mimosa diplotricha* var. *diplotricha* and *Andropogon gyanus*), which are highly invasive and difficult to control. These species were located near the waste management facilities and northern perimeter fence, potentially attributed to the proximity of these areas to the public road. The 2019 survey indicated the Priority 3 weed *Passiflora foetida* and Priority 2 weed *Clitoria ternatea* as widespread weed species present in relatively high abundance with four to six individuals observed along transects in most areas surveyed. Also widespread and present in high abundance in the LNG Plant area were *Macroptilium atropurpureum*, *Tridax procumbens*, *Stachytarpheta jamaicensis*, *Euphorbia heterophylla*, and *Mimosa pudica*.

7.2.2 Terrestrial fauna

The field surveys conducted for the PNG LNG Project included non-volant mammals, birds and herpetofauna (frogs and reptiles). The 2019 survey was limited only to wallabies to estimate wallaby population size within the LNG Plant site security fence based on an apparent increase in the abundance of agile wallabies observed by site personnel at the LNG Plant (Appendix K LNG Plant Weed Survey).

The 2008 baseline fauna survey recorded few fauna at the LNG Plant site mainly due to the disturbed overall habitat quality. The exceptions to this are the estuarine, fresh water and terrestrial habitat of the Vaihua River, providing a seasonal habitat for various waterbirds, including migratory shorebirds. The estuaries support a higher abundance and diversity of aquatic fauna than any other habitat on the LNG Plant site. The 2008 surveys identified: two species of mammal, six reptiles and 71 species of bird. Twenty-two bird species recorded in 2009 were not observed in 2008, taking the total number of bird species recorded on site to 92. Among those birds recorded for the first time in 2009 was the only International Union for Conservation of Nature (IUCN)-listed terrestrial vertebrate recorded in the Terrestrial Lease Area thus far – the Near Threatened Beach Thick-knee (*Esacus giganteus*) (Woxvold 2009). Survey findings can be summarised as:

- None of the three native non-volant species recorded or reported during the 2008 PNG LNG Project baseline survey are of national or international conservation concern.
- Twenty-three bat species could occur in study area, including seven IUCN listed species (Woxvold 2008).
- The 2008 study recorded eighteen wetland bird species in these habitats, including three national protected species and 10 migratory Palearctic (a region comprising Europe and Asia north of the Himalayas and North Africa) shorebirds (Woxvold 2008). The 2009 survey recorded a total of 70 bird species from 30 families including four nationally protected species.
- A total of three frog and eight reptile species were documented in the study area in 2008. All except one (*Cryptoblepharus yulensis*) are common species in the savanna habitats of southern Papua New Guinea. None are IUCN-listed and none are protected under the *Fauna (Protection and Control) Act 1966*.
- The LNG Plant site comprises ideal habitat for wallaby populations (see Plate 7.9) particularly where natural vegetation strips have been retained and large expanses of lawns are maintained. During the

2019 survey, between 25 and 48 individuals were counted. The presence of juveniles in the LNG Plant site indicates a healthy and reproducing population of wallabies. Effects of overpopulation of wallabies were not noticeable at the time of the survey in 2019.

Based on the construction and operation of the LNG Plant, it is expected that species composition, as well as habitat availability, observed during the 2008/2009 surveys have changed.

Detailed descriptions of the previous survey findings can be found in the PNG LNG EIS.

7.3 FRESHWATER AQUATIC BIOLOGICAL ENVIRONMENT

The aquatic biological environment includes aquatic features and habitats, aquatic flora and fauna (fish, macroinvertebrates and other fauna) that contribute to aquatic biodiversity.

The environmental studies carried out as part of the PNG LNG Project included a series of aquatic biological surveys undertaken in 2008 (Hydrobiology 2008). Three freshwater environments were surveyed including (Figure 7.7):

- Vaihua River
- North Vaihua River
- Karuka Creek.

7.3.1 Freshwater aquatic habitats

Three primary aquatic habitat types were identified within the LNG Plant and surrounding area:

- Freshwater rivers and streams
- Hypersaline wetlands (mudflats and saltflats)
- Estuarine tidal creeks and mangroves.

The following sections describe the freshwater rivers and streams. The hypersaline wetlands and estuarine tidal creeks and mangroves are described in Chapter 8 Receiving Environment: Marine.

The Vaihua and North Vaihua rivers and Karuka Creek are freshwater habitats that occur within the LNG Plant site. There are no freshwater lakes in the study area with the closest lakes located 6 km to the north-east.

In June 2008 (the height of the dry season) at the time the studies were conducted, the main channels of some watercourses had low flows and many other watercourses were dry channels, with remaining isolated pools. Important refuge habitats for freshwater aquatic life are provided by these permanent remnant pools during the dry season. Watercourses in the LNG Plant areas are generally classified as ephemeral due to the low rainfall and high evaporation. There may be some groundwater recharge of surface water within the main channels of watercourses based on the observation during the field surveys of some seemingly isolated pools that had perceptible but small flows.

Flows from watercourse main channels to the estuaries return during the wet season (December to March), and overbank flooding of the floodplain areas occurs, forming temporary wetlands over the salt flats and mudflats.

7.3.2 Freshwater fish fauna

Five freshwater sites in the Vaihua and North Vaihua rivers, and Karuka Creek were sampled as part of the PNG LNG Project EIS during the baseline survey (Hydrobiology 2008). The fish fauna sampled, visually

observed, or both, are listed in Table 7.9, none of which are nationally or internationally threatened. These species are common to coastal rivers and streams of southern Papua New Guinea.

Table 7.9 Freshwater fish species

Common name	Species name	Family name
Tilapia	<i>Oreochromis mossambica</i>	Cichlidae
Snakehead gudgeon	<i>Ophieleotris aporos</i>	Eleotridae
Papua rainbowfish	<i>Melanotaenia papuae</i>	Melanotaenidae
Goby	Goby sp.7	Gobiidae

Source: Hydrobiology (2008).

7.3.3 Macroinvertebrate fauna

Electroshocking and seine netting were used in the 2008 survey to sample large macroinvertebrate fauna in the freshwater sites. Freshwater benthic macroinvertebrate fauna were sampled separately by grab sampling of bottom sediments.

Two species of decapod crustaceans were visually observed in the rivers and streams draining the Project site. The giant freshwater prawn (*Macrobrachium lar*) was observed in the Vaihua River and the North Vaihua River and an unidentified prawn (*Macrobrachium sp.3*) was observed in the Karuka Creek. It is likely that other freshwater prawn species are present in freshwater environments of the LNG Plant site areas and that low species numbers were observed due to the limited efficacy of electroshocking in freshwater pools.

7.3.4 Other aquatic fauna

Other aquatic fauna or water-associated fauna that were present or expected to occur in the LNG Plant and surrounding environment are described below.

7.3.4.1 Freshwater turtles

The ephemeral nature of the watercourses within the LNG Plant and surrounds is not likely to contain freshwater turtles, which tend to rely on perennial river and stream habitats. While no freshwater turtles were observed during the survey, during the dry season remnant pools may act as refuges for turtle species.